TECHNICAL NOTE

U.S. DEPARTMENT OF AGRICULTURE NATURAL RESOURCES CONSERVATION SERVICE

ENGINEERING # 6 **SPOKANE, WASHINGTON**

"FILTER DIAPHRAGMS FOR CO-01 STRUCTURES"

BACKGROUND

Danny McCook, of the Fort Worth Soil Mechanics Center, developed the attached Technical Note. The purpose of the Technical Note is to provide guidance for designing filter diaphragms for earthfill structures designed using Conservation Practice Standard 378, Ponds. Design of larger structures is governed by the provisions of TR60, Earth Dams and Reservoirs.

NATURAL RESOURCES CONSERVATION SERVICE
NATIONAL DESIGN CONSTRUCTION AND SOIL MECHANICS CENTER
TECHNICAL NOTE - FILTER DIAPHRAGMS FOR CO-01 STRUCTURES

BACKGROUND

This Technical Note provides guidance for designing filter diaphragms for earth fill structures that fall under the 378 Conservation Practice Standard. Design of larger structures is governed by provisions in TR60.

Conduits that extend through and under embankment structures are a discontinuity in the structure. Several common problems which are caused by conduits are discussed in following sections.

Hydraulic fracture is one problem that is sometimes associated with conduits. Cracking in the earth fill surrounding conduits can result in pathways for water to flow. Hydraulic fracture is discussed in more detail in a following section.

Conduits hinder the compaction of soils. If soil is not compacted properly near conduits, paths for water to flow more easily through and under the surrounding earthfill can occur. Compacting soil under the haunches of pipes that are laid without a concrete cradle is difficult. Operating equipment near the conduit must be limited to avoid damaging the pipe. Hand held equipment is often used to avoid damage by larger compaction equipment. Hand-compacted soil may have different properties than machine-compacted soils. Differences in compacted conditions between hand placed and machine compacted soils sometimes also causes problems.

Two design measures have commonly been used to address the concern about flow through the earth fill surrounding conduits. They are (1) anti-seep collars and (2) filter diaphragms. Both measures are permissible under 378 requirements and they are discussed in detail in following sections. This information should be considered in selecting which method is most appropriate for a given site.

ANTI-SEEP COLLARS

Anti-seep collars have been the traditional method used to block the flow of water at the interface of the conduit and the backfill surrounding the conduit. Anti-seep collars have two intentions. One purpose is to prevent flow along the interface between the conduit and the compacted backfill.

The other is to increase the length of the flow path for the seepage water. By forcing water to flow a greater distance, the theory is that more hydraulic head is dissipated. This reduces the energy of the water where it exits the embankment and foundation at the downstream toe of the dam. The theory of increasing the length of the flow path to decrease the potential for piping was based on experience with concrete gravity dams. Some design guidance suggests using enough collars to increase the flow path length by 15 to 20 percent.

Anti-seep collars are typically constructed of metal, concrete, or plastic. Often, the same material is used for the collars as are used for the conduit itself.

Figure 1 shows three different types of anti-seep collars:

Figure 1. Three Different Materials Used for Anti-seep Collars

The NRCS criteria for larger embankments is contained in TR60. It was revised in October 1985 as an amended TR60. The revision required that anti-seep collars no longer be used as a design measure for seepage control for dams designed under TR60. This amendment required that filter diaphragms be substituted for anti-seep collars in the design of all structures governed by this standard. Filter diaphragms are discussed in detail in following sections.

Conservation Practice Standard 378, Ponds, which was last revised in July, 2002, is the current criterion for smaller embankments. It still allows use of anti-seep collars in structures that fall under that Standard. The current guidance given in 378 states that:

> ***"Seepage along pipes extending through the embankment shall be controlled by use of a drainage diaphragm, unless it is determined that anti-seep collars will adequately serve the purpose."***

The term "unless it is determined that anti-seep collars will adequately serve the purpose" is not defined in any detail in CPS 378. Discussion in this technical note should provide additional guidance.

Reasons that anti-seep collars were discontinued on TR 60 size embankments in 1985 were:

- A significant number of failures of embankments occurred even though it was certain that the collars were properly installed and that the surrounding backfill was adequately compacted.

- Most of the failures occurred shortly after construction of the dam, when the pool filled quickly for the first time. Obviously, not enough time had elapsed for seepage to cause the failures. Flow of water through cracks in the dams was attributed as the cause of the failures. In many cases, the anti-seep collars were still intact and it was obvious that the water flowed through the earth fill some distance from the conduit, not along the conduit.

- Studies of the failed embankments indicated that the pathway for the water that eroded a tunnel through the dam was not directly along the conduit, but in the earth fill above or to either side of the conduit. Many of these failures occurred in embankments constructed using dispersive clay soils.

Figure 2. Photographs of Failed Embankments with Anti-seep Collars

Dispersive clays are extremely erodible soils and cracks in the earthfill surrounding the conduit were attributed to have caused these failures. Soil Mechanics Note SM-13 discusses dispersive clays in detail, including performing field tests to identify them.

Following sections discuss cracking of earth fills near conduits. Figure 2 above shows several typical embankments that failed even though properly installed anti-seep collars were included in their designs. Soils were well compacted around the conduit.

The Lincoln Nebraska soil mechanics laboratory initiated a testing program on filters for soils in the 1980's. That testing demonstrated the efficacy of a sand filter in intercepting and sealing flow through cracks in an earth fill, thus preventing subsequent erosion.

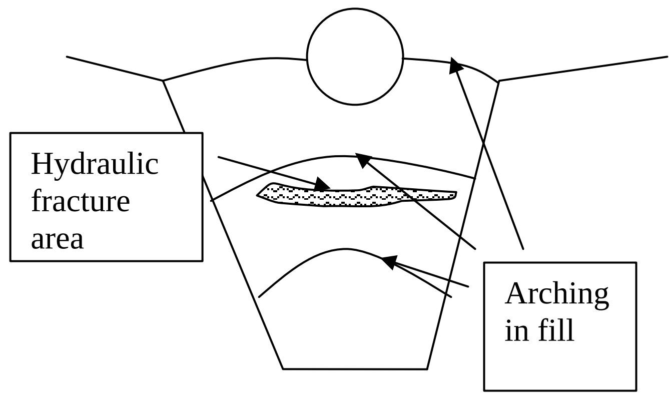
HYDRAULIC FRACTURE

The primary cause of cracks in earthen embankments is hydraulic fracture. When cracks occur, they can provide flow paths for internal erosion. Hydraulic fracture of an earth fill can have several causes as follows:

- If desiccation cracks are not carefully removed from fill surfaces before placing the next layer of fill, a plane of weakness is created in the fill that can later hydraulically fracture easily.

- Hydraulic fracture can also occur from arching. Arching occurs when low lateral stresses result from differential settlement. The pressure of reservoir water can hydraulically fracture earthfill if the pressure caused by the reservoir water exceeds the lateral stress on the soil. Hydraulic fracture usually creates a horizontal plane of weakness in the fill.

- Figure 3 illustrates arching in an earth fill where a trench is backfilled beneath a conduit. This is typical for sites where conduits are installed. Arching occurs as stresses in the soil in the trench are transferred by friction to the sides of the trench. This allows the low stress condition in the trench soils that is susceptible to hydraulic fracture



Hydraulic fracture often causes horizontal cracks in an earth fill. This hydraulic fracturing phenomenon often occurs during the first filling of the reservoir or the first filling to an unprecedented elevation. Factors that can contribute to hydraulic fracturing are:

1. Sharp changes in bedrock profile near conduits can cause differential settlement, particularly if compressible soil horizons overly the bedrock.

Differential foundation settlements as low as 1.0'/100' of horizontal distance is thought capable of creating conditions conducive to hydraulic fracturing. [1] Differential settlement often causes arching in the soils near the anomalies.

2. Conduits are often installed in trenches to attain the required invert elevation for draining a reservoir through the conduit. Trenches that are transverse to the centerline of the embankment can create differential settlement that can cause hydraulic fracture. If the trench is backfilled with soil compacted to a high density and low water content compared to the adjacent foundation soils, the trench soils will have very different compressibility than the foundation soils.
3. Embankment soils compacted at or below optimum water content are more likely to crack if subjected to differential foundation movements.
4. Low cohesion soils are more susceptible to cracking than higher plasticity soils. Soils considered desirable for the central cores of embankments have a plasticity index (PI) greater than 10. The higher PI means the soils are more flexible and have a reduced hazard of cracking.
5. Very high plasticity soils are more susceptible to developing drying cracks in fill surfaces during interruptions of fill placement. If desiccation cracks are not removed before placing subsequent fill layers, they can provide a pre-existing weakness subject to hydraulic fracture.
6. Dispersive clays are probably no more subject to hydraulic fracture than other soils, but these soils are extremely erodible. Hydraulic fracture is more likely to cause a failure in dispersive clay earth fills than with other soils.

Factors that reduce the probability of hydraulic fracture of embankments include the following:

1. Placement at water contents at least two percent above Standard Proctor optimum water content is thought to increase the flexibility of the compacted cohesive fill soils particularly.
2. Flattening the slopes of any excavation transverse to the embankment centerline is helpful in preventing differential settlement. Usually, stream channel slopes and excavations transverse to the embankment should be flattened to at least 3H: 1V slopes. If the embankment soils are especially unfavorable (dispersive clays for instance), slopes no steeper than 4H: 1V are recommended.
3. Conduits should not be located near the abutments of sites where bedrock profiles are sharp to avoid differential settlement problems.

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[1] Sherard, James L., Rey S. Decker, and Norman L. Ryker. "Hydraulic Fracturing in Low Dams of Dispersive Clays," Proceedings of ASCE Specialty Conference, Performance of Earth and Earth-Supported Structures, Volume 1, Part 1, Purdue University, June, 1972. Pp. 653-689.

FILTER DIAPHRAGM

Definition. A filter diaphragm is a designed zone of filter material (usually well-graded, clean sand) constructed around a conduit. It has become a standard defensive design measure to prevent problems associated with seepage or internal erosion in earth fill surrounding the conduit.

Purpose. The purpose of a filter diaphragm is to intercept cracks that may occur in compacted fill near conduits. The purpose of the diaphragm is to intercept cracks in the surrounding fill or at the interface between the conduit and the surrounding fill. Water flowing along cracks in the fill surrounding the conduit may erode soil from the sides of the crack. But, when the flow reaches the designed gradation filter material in the diaphragm, the eroded soil particles will lodge on the upstream face of the diaphragm.

Filter Mechanism. The filter cake that develops where the crack meets the diaphragm almost complete prevents any subsequent flow in the crack and in effect seals the crack. The intent of a filter diaphragm is not to act as a drainage zone, but it is as a crack intercepting and sealing zone.

The theory behind the action of a filter diaphragm is based on extensive testing performed in the NRCS Lincoln, Nebraska laboratory in the 1980's. Tests demonstrated that even highly erosive clay soils with a hole created in them would not erode further when protected by a properly designed filter layer of sand.[2]

[2] Sherard, J.L.", "Critical Filters for Impervious Soils," ASCE Journal of Geotechnical Engineering, Vol. 115, No. 7, July, 1989.

By intercepting cracks, the filter collects soil particles eroded from the face of the crack upstream of the diaphragm. The collected particles create a filter caked on the diaphragm surface that seals the crack and prevents further flow through the crack.

DESIGN OF FILTER DIAPHRAGM

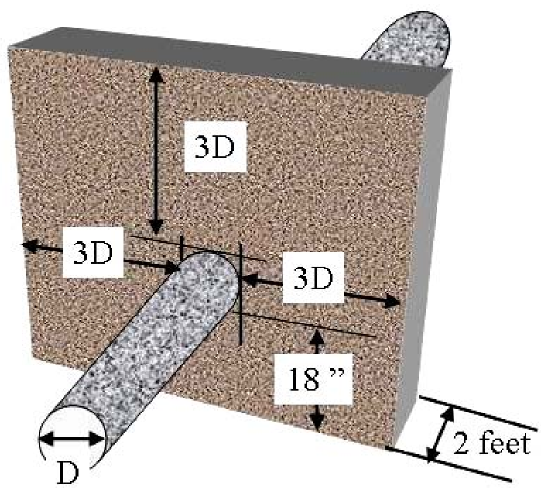
The following recommendations and discussion pertain to designs where the embankment does not contain a chimney filter. A chimney filter can serve the combined purpose of a filter diaphragm to protect against flow around the conduit and to protect flow through other sections of the dam. Some embankments may be designed without internal drainage systems such as chimney filters or transition zones.

If an embankment is low or intermediate hazard and is constructed of soils resistant to internal erosion and piping, the cost of an internal chimney filter is usually not justified.

For most dams, however, a diaphragm of filter sand surrounding the conduit is a low cost insurance against failures. The filter diaphragm provides considerable added confidence that water flowing through the embankment outside the conduit will not erode the soils and cause a failure. The cost of a filter diaphragm is not ordinarily much greater than the cost of anti-seep collars that are eliminated by using the diaphragm.

Figure 4 summarizes the recommended dimensions for a filter diaphragm as discussed in Conservation Practice Standard 378. The dimensions are usually adequate wn may be inadequate for some situations. Because the intent of the diaphragm is to intercept potential cracks in the earth fill, in some conditions, the diaphragm should be extended. Figure 4 shows situations where the dimensions of a filter diaphragm should be adjusted.

Figure 4. Filter Diaphragm Dimensions



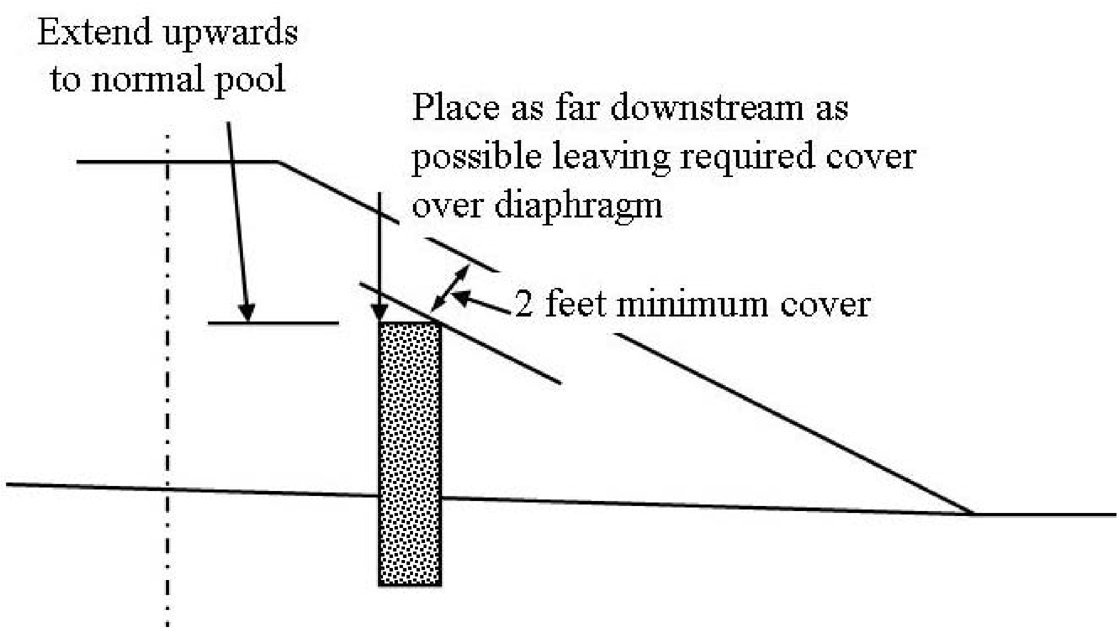


Figure 5. Location of Filter Diaphragm in Embankment

Figure 6. Example of situation in which standard recommended dimensions for filter diaphragm should be expanded. In this sketch, the conduit is placed in a trench, and the 3D lateral dimension suggested for the diaphragm does not extend into the contact between the earthfill and natural foundation. The diaphragm should be widened to intercept possible cracks at that interface.

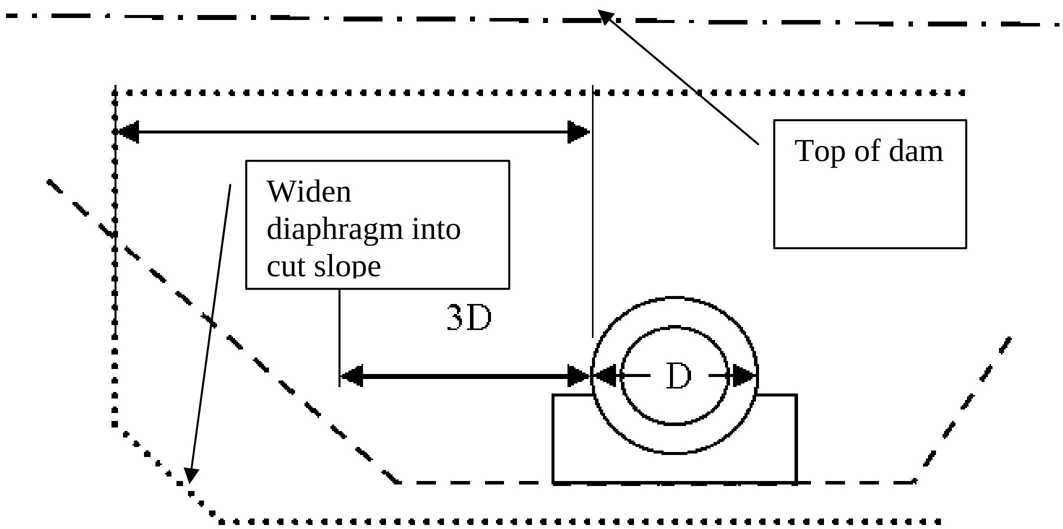
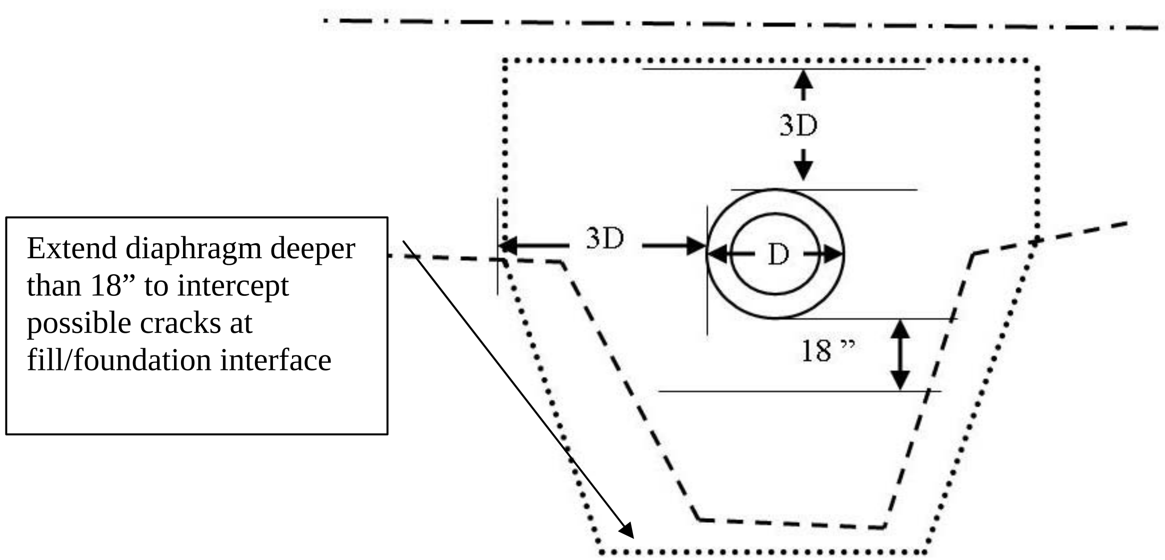


Figure 7. Example of situation in which standard recommended dimensions for filter diaphragm should be expanded. In this sketch, the conduit is placed in the area of a deep v-shaped gulley. The bottom dimension suggested for the diaphragm does not extend into the contact between the earthfill and natural foundation. The diaphragm should be deepended to intercept possible cracks at that interface.



Designs should incorporate an outlet for the filter diaphragm. Conservation Practice Standard 378 requires that, "The drainage diaphragm shall be outletted at the embankment downstream toe using a drain backfill envelope continuously along the pipe to where it exits the embankment." Some designs incorporate a zone of gravel in the outlet and some also include a perforated pipe.

FILTER AND DRAIN GRADATION.

The gradation of the sands used in the filter diaphragm is important if they are to function properly. Conservation Practice Standard recommends that "The drainage diaphragm shall consist of sand meeting the requirements of ASTM C-33, for fine aggregate. If unusual soil conditions exist such that this material may not meet the required filter or capacity requirements, a special design analysis shall be made."

Standard filter design methods such as the NRCS design procedure shown in the National Engineering Handbook, Part 633, Chapter 26 should be used to design filters.

Materials suitable for filter diaphragms will almost never be available on site and are usually purchased from concrete aggregate suppliers.

In addition to having good filter properties, sands used to construct diaphragms should also be able to deform and fill any cracks that may occur. The term used to describe sands with this property is "self-healing". Vaughan (1982) describes a simple test for evaluating the "self-healing" properties of filters.

Tests such as the no erosion filter test described by Sherard [3] may be used to judge the adequacy of filter designs for large, important projects.

SPECIFICATIONS AND DENSITY QUALITY CONTROL FOR FILTER SANDS

INTRODUCTION.

Compacting filter sand used in filter diaphragms is important to prevent the filter diaphragm from settling when it becomes saturated. Some fine sands are particularly susceptible to bulking. Bulking occurs when sand at a water content of about 4 to 10 percent is dumped into a trench. At these water contents, fine sands develop strong capillary forces between the particles that resist rearrangement and compaction of the sands. The result is that the sands are in a very loose condition.

If the sands are not then compacted or wetted to eliminate the bulking behavior, they will be very loose in the trench. Future saturation will cause collapse type settlement that could leave a void above the sand.

[3] Sherard, J.L, and L.P. Dunnigan, "Critical Filters for Impervious Soils," Journal of Geotechnical Engineering, Vol. 115, No. 7, July, 1989, pp. 927-946.

Figure 8 shows a lab test used to evaluate bulking. The sand in the cylinder on the top is dumped into the cylinder at a bulking water content. The picture on the bottom shows the sand after it was saturated. Note the before volume of the sand was about 480 cc's and the volume of the sand after wetting is about 330 cc's.

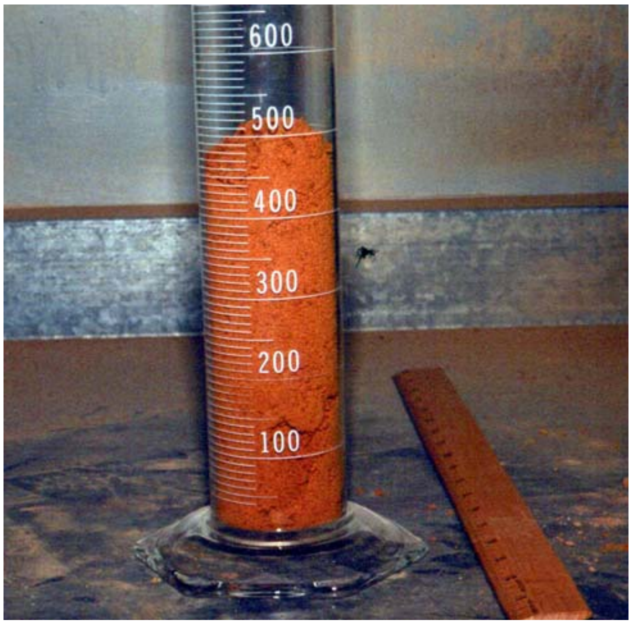
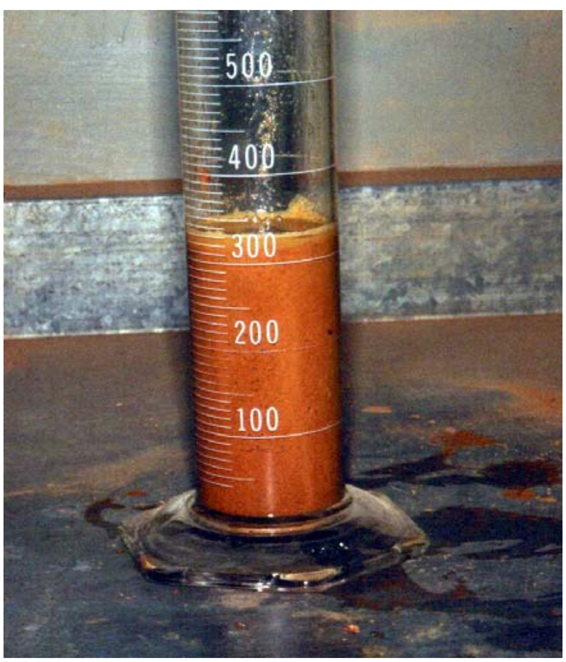


Figure 8. Bulking Demonstration



If sands bulk when placed into a trench for construction of a filter diaphragm, one approach is to flood and thoroughly wet the sands. Another approach is controlled compaction of the filter diaphragm sands. Either method or both may be employed on a particular project. Using these methods is important to prevent settlement of the sands on wetting. Compaction of gravels has less emphasis because they are not susceptible to bulking.

Compaction for sand filters is usually specified by two principal types of specifications. The two types of specifications used for controlling compaction of sands and gravels are "Method" and End Result". For 378 projects, using "End Result" specifications that involve performing field tests of the sands' compacted density would seldom be warranted. This document then only discusses the "Method Placement" for specifying compaction of filter diaphragms.

METHOD PLACEMENT SPECIFICATION.

A "Method Placement" specification requires the filter sand to be compacted in a specified manner. It does not require a measured density or water content to be obtained. Method specifications typically require a particular type of equipment that is operated in a specified manner. The specification assumes that the designer has previous favorable experience with a specified method and has confidence that the filter sand will have adequate properties if it is compacted using these procedures.

For filter diaphragms, using smaller compaction equipment such as walk behind vibratory rollers and plate compactors may be required if working space is limited. Figure 9 shows examples of small vibratory compaction equipment that may be specified for filter diaphragms.

Figure 9. Examples of small vibratory compactors used in compacting filter diaphragms.

Attachment 1 has a summary of major manufacturers and a list of equipment that may be suitable for compacting filter diaphragms.

An example of a Method Placement specification is as follows:

Drainfill shall be placed uniformly in layers not to exceed 8 inches thick before compaction. Each layer shall be thoroughly wetted prior to compaction.

Each layer of drainfill shall be compacted by a minimum of 2 passes of a vibratory plate compactor weighing at least 160 pounds. The compactor shall have a minimum centrifugal force of 2,450 pounds at a vibrating frequency of no less than 5,000 cycles per minute (or by a minimum of 2 passes of a vibratory smooth wheeled roller weighing at least 325 pounds with a centrifugal force of 2,250 pounds at a vibrating frequency of no less than 4,500 cycles per minute).

The material shall be placed to avoid segregation of particle sizes and to ensure the continuity and integrity of all zones. No foreign material shall be allowed to become intermixed with or otherwise contaminate the drainfill.

Traffic shall not be permitted to cross over drains at random. Equipment cross-overs shall be maintained, and the number and location of such crossovers shall be established and approved before the beginning of drainfill placement. Each crossover shall be cleaned of all contaminating material and shall be inspected and approved by the engineer before the placement of additional drainfill material.

Any damage to the foundation surface or the trench sides or bottom occurring during placement of drainfill shall be repaired before drainfill placement is continued.

The upper surface of drainfill constructed concurrently with adjacent zones of earthfill shall be maintained at a minimum elevation of 1 foot above the upper surface of adjacent earthfill.

END RESULT SPECIFICATION

An "End Result" specification requires the filter sand to be compacted to a specified value of dry density. Usually, the required density is specified by reference to a standard test. The traditional method for specifying filter sand compaction uses relative density terminology and tests. ASTM Standard Test Method D4253 describes the test used to measure the Minimum Index Density of the filter sand, ASTM Standard Test Method D4254 describes the test for Maximum Index Density of the sand.

QUALITY CONTROL

The only quality control required for method specifications may be documented observations of the methods used for filter placement.

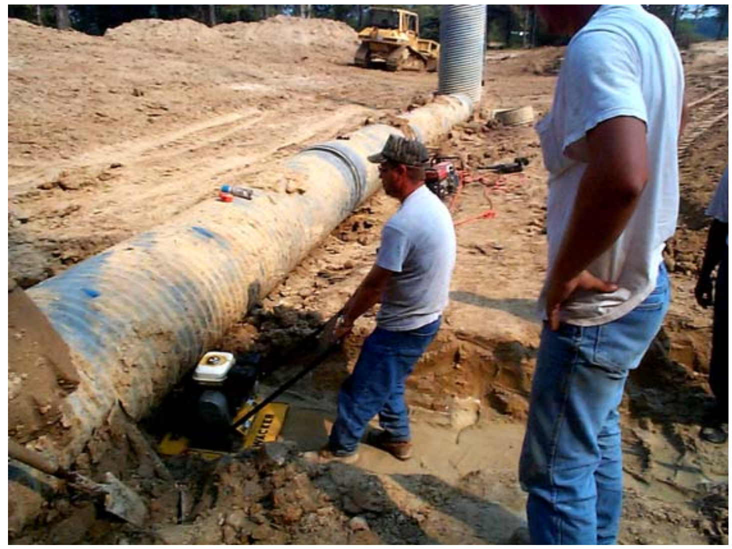
INSTALLATION OF FILTER DIAPHRAGMS

Following photographs show a filter diaphragm being installed at a site as a repair measure. This embankment failed because it was constructed of dispersive soils and anti-seep collars were used rather than a filter diaphragm. If is unlikely that the failure would have occurred if the original construction had used a filter diaphragm.

Figure 10. Failed embankment.

Metal anti-seep collars can be observed in the bottom of the erosion tunnel in the embankment. This dam failed on first filling. The soils were plastic CL soils that were highly dispersive.

Figures 11, 12, and 13. Installing filter diaphragm under and adjacent to pipe. Small vibratory plate compactor is being used to compact sand in the diaphragm. The diaphragm trench has been excavated with a backhoe bucket and is about 3 feet wide.



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